In-situ observation of chondrule formation during levitation

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Chondrules are small silicate droplets which were formed at 4.6 billion years ago. And they are thought to be crystallized from very large supercooled silicate melt, because of its containerless condition in space. However, crystallization experiments at levitated silicate droplet were very few (eg. Tsukamoto et al. 1999). So, in order to understand the crystallization process of chondrules in containerless condition, we have done the crystallization experiments from supercooled silicate melt droplet by utilizing gas jet levitator. Additionally, we tried to inject dust particles into levitated droplet as heterogeneous nucleation center, because there were many dust particles around chondrule melts and previous experiments showed difficulty of nucleation even under large supercooling condition.

The starting materials were forsterite (Mg2SiO4) and enstatite (MgSiO3) glass spherule (diameter = 2-3 mm), which were made of MgO and SiO2 powder reagents. Starting material was set at the top of nozzle (diameter = 2 mm) of the gas jet levitator and then levitated by introducing Ar gas from the nozzle. The levitated glass spherule was melted by CO2 laser (100 W) irradiation. The melt temperature was measured by pyrometer (spot size = 0.9 mm, wavelength = 0.8-1.6 mm). By adjusting the CO2 laser power supply, the melt temperature was decreased and then kept at a certain supercooling temperature. The nucleation process from the supercooled melt was observed by high speed CCD camera equipped with macro lens. To investigate the seeding effect, dust particles were accreted to the supercooled melt.

The forsterite melt nucleated easily below 1100 K (supercooling temperature is 800 K) without seeding. However, above 1100 K, forsterite nucleation rate suddenly decreased and finally supercooled forsterite melt was stabilized. On the other hand, enstatite did not nucleated from supercooled melt at any temperature region without seeding.

The difference of the seeding effect between forsterite and enstatite melt was also observed. By seeding of dust particles, forsterite nucleated at in any temperature region. However, enstatite nucleated at only supercooling temperature (dT) = 550-1000 K. Especially at smaller than 550 K of dT, dissolution after growth of seed crystals be observed as CCD camera image and small recalescence. Forsterite nucleated from enstatite melt as stable phase at 550-700 K of dT and enstatite nucleated from enstatite melt as metastable phase at 700-1000 K of dT. Especially radial texture was crystallized from enstatite melt at 900-1000 K of dT.

These results showed forsterite melt could nucleate more easily than enstatite melt. This reason is explained due to difference in property of liquid between forsterite melt and enstatite melt. Especially, viscosity of forsterite melt is smaller than enstatite melt because the crystal structure of enstatite melt is complex.

Since at larger than 1000 K of dT, the viscosity of enstatite is so large, the melt becomes glass. As reason of dissolution of seed crystals at smaller than 550 K of dT, it was thought that seed crystals were dissolved for latent heat of crystallization. The theoretical value of latent heat was calculated by enthalpy of fusion over specific heat. It was 600 K. So, it was enough to heat up liquids of enstatite.

This study showed that follow about crystallization process of chondrules. Chondrule melts were cooled quickly below liquidus, however nucleation was not occurred easily. Because chondrule melts had to nucleate, heterogeneous nucleation was occurred by contact with dust particles. Especially, radial pyroxene chondrule had to nucleate enstatite from enstatite melt as metastable phase. So, radial pyroxene chondrule melt had to be cooled at very large supercooling temperature (eg. enstatite composition is 700 K).